GEARTECH Report No. 2025

Comparison of ISO 6336 and AGMA 2001 Load Capacity Ratings for Wind Turbine Gears-Torque Reserve Ratio

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TOWNSEND MT 59644

INTRODUCTION

The AGMA/AWEA Wind Turbine Committee is considering guidelines for gear rating in accordance with ISO 6336 and AGMA 2001 in AGMA/AWEA 6006-AXX [1]. However, ISO 6336 and AGMA 2001 ratings can differ significantly [2,3]. These differences must be addressed to develop reliable guidelines.

OBJECTIVE

This study compares ISO 6336 and AGMA 2001 ratings from GEARTECH Report 1974 [2] with ratings obtained by the AGMA Wind Turbine Committee. The objective is to expand the analysis from six gearsets of the AGMA study to all eighteen gearsets from GEARTECH Report 1974.

SCOPE

Eighteen actual wind turbine gearsets from GEARTECH Report 1974 [2] were considered.

RATING STANDARDS

All gearsets were rated in accordance with ISO 6336 [4,5,6,7] and AGMA 2001 [8].

SOFTWARE

All gearsets were rated using the ISO 6336 computer program [9] and AGMA218 [10]. Gear and hob geometries were calculated with GEARCALC [11].

RATING PARAMETERS

To obtain rating comparisons independent of derating factors, input data for the ISO 6336 and AGMA218 computer programs were prepared with the same derating factors for application, load distribution, and dynamics. Additionally, the same gear and hob geometry was used for both programs.

ALLOWABLE TORQUE RATIO FROM GEARTECH REPORT 1974

GEARTECH Report 1974 [2] summarized load capacity ratings for eighteen actual wind turbine gearsets. ISO 6336 and AGMA 2001 ratings were compared for the same gear geometry and derating factors. Calculations were based on a required life of 175,000 hours and an application factor of K_A = 1.3.

Allowable Torque Ratios were defined as the ratio of the allowable torque according to AGMA 2001 to the allowable torque according to ISO 6336 as follows:

For Durability

$$\frac{Ta}{Ta_{ISO}} = \left(\frac{SH_{AGMA}}{SH_{ISO}}\right)^2$$

For Strength

$$\frac{Ta}{Ta_{ISO}} = \left(\frac{SF_{AGMA}}{SF_{ISO}}\right)$$

Table 1 summarizes the Allowable Torque Ratios from GEARTECH Report 1974.

Table 1- Allowable Torque Ratios Ta / Ta_{ISO} from GEARTECH Report 1974

Gearset Ident. No.	Allowable Torque Ratios	
	Durability	Strength
2	0.586	0.577
4	0.579	0.562
5	0.587	0.565
6	0.626	0.589
7	0.574	0.565
11	0.563	0.660
12	0.669	0.775
13	0.601	0.573
14	0.560	0.581
15	0.643	0.644
17	0.641	0.654
18	0.666	0.671
h08	0.631	0.631
h12	0.714	0.816
h15	0.554	0.633
h19	0.565	0.678
h25	0.565	0.609
h30	0.565	0.569

TORQUE RESERVE RATIO FROM AGMA STUDY

The AGMA Wind Turbine Committee compared ISO 6336 and AGMA 2001 gear ratings. They choose six gearsets from GEARTECH Report 1974 and used actual load spectra. The AGMA study used the following procedure:

1. AGMA torque reserve- Run Miner's Rule according to AGMA 2001 and iterate the application factor, K_A, to obtain 175,000 hours life.

   $T_{HA} = K_A$ for pitting life of 175,000 hours
   $T_{FA} = K_A$ for bending life of 175,000 hours

2. ISO safety factors- Run Miner's Rule according to ISO 6336 using T_{HA} and T_{FA} from step 1 in place of K_A. Iterate safety factors S_H and S_F to obtain 175,000 hours life.

   S_H = safety factor for pitting life of 175,000 hours
   S_F = safety factor for bending life of 175,000 hours

3. ISO/AGMA Torque Reserve Ratio- Calculate ISO/AGMA Torque Reserve Ratio using ISO safety factors from step 2.

   $T_{HI} / T_{HA} = (S_H)^2$ Torque Reserve Ratio for durability
   $T_{FI} / T_{FA} = S_F$ Torque Reserve Ratio for strength

Table 2 summarizes the Torque Reserve Ratios from the AGMA study.

Table 2- Torque Reserve Ratios from AGMA Study

Gearset Ident. No.	Torque Reserve Ratios	
	Durability T_{HI} / T_{HA}	Strength T_{FI} / T_{FA}
6	1.38	1.51
13	1.44	1.47
18	1.28	1.23
h12	1.21	1.12
h15	1.53	1.41
h30	1.56	1.69

COMPARISON OF GEARTECH REPORT 1974 AND AGMA STUDY

Table 3 compares the *Allowable Torque Ratios* for durability from GEARTECH Report 1974 with the *Torque Reserve Ratios* from the AGMA study. The third column in Table 3 shows the inverse of the Allowable Torque Ratio. The last column shows values obtained by dividing the inverse of the Allowable Torque Ratios (third column) by the Torque Reserve Ratios (fourth column). The average of the six values in the last column is 1.16.

allowable torque ratio (from Table 1)

inverse of allowable torque ratio

torque reserve ratio
(from Table 2)

Table 3- Comparison of Allowable Torque Ratios and Torque Reserve Ratios for Durability

1	2	3	4	5
Gearset Ident. No.	Report 1974 Ta / Ta_{ISO}	Report 1974 Ta_{ISO} / Ta	AGMA Study T_{HI} / T_{HA}	Ratio $\frac{Ta_{ISO} / Ta}{T_{HI} / T_{HA}}$
6	0.626	1.597	1.38	1.16
13	0.601	1.664	1.44	1.16
18	0.666	1.502	1.28	1.17
h12	0.714	1.401	1.21	1.16
h15	0.554	1.805	1.53	1.18
h30	0.565	1.770	1.56	1.13
			average	1.16

inverse of allowable torque ratio divided by torque reserve ratio

Using the average value of 1.16 obtained from Table 3, Torque Reserve Ratios are calculated from Allowable Torque Ratios from GEARTECH Report 1974 as follows:

$$\frac{T_{HI}}{T_{HA}} = \left(1.16 * \frac{T_a}{T_{aISO}}\right)^{-1}$$

Torque Reserve Ratios calculated with this equation are shown in the third column of Table 4 and plotted in Figure 1.

Table 4- Torque Reserve Ratios calculated from Allowable Torque Ratios from GEARTECH Report 1974 for Durability

Gearset Ident. No.	Report 1974 Ta / Ta_{ISO}	Report 1974 T_{HI} / T_{HA}	AGMA Study T_{HI} / T_{HA}
2	0.586	1.47	
4	0.579	1.49	
5	0.587	1.47	
6	0.626	1.38	1.38
7	0.574	1.50	
11	0.563	1.53	
12	0.669	1.29	
13	0.601	1.43	1.44
14	0.560	1.54	
15	0.643	1.34	
17	0.641	1.34	
18	0.666	1.29	1.28
h08	0.631	1.37	
h12	0.714	1.21	1.21
h15	0.554	1.56	1.53
h19	0.565	1.53	
h25	0.565	1.53	
h30	0.565	1.53	1.56

Table 4 shows the calculated values match AGMA values within 2% for the six gearsets of the AGMA study.

Table 5 compares the *Allowable Torque Ratios* for strength from GEARTECH Report 1974 with the *Torque Reserve Ratios* from the AGMA study. The third column in Table 5 shows the inverse of the Allowable Torque Ratio. The last column shows values obtained by dividing the inverse of the Allowable Torque Ratios (third column) by the Torque Reserve Ratios (fourth column). The average of the six values in the last column is 1.13.

allowable torque ratio (from Table 1)

inverse of allowable torque ratio

torque reserve ratio (from Table 2)

Table 5- Comparison of Allowable Torque Ratios and Torque Reserve Ratios for Strength

1	2	3	4	5
Gearset Ident. No.	Report 1974 Ta / Ta_{ISO}	Report 1974 Ta_{ISO} / Ta	AGMA Study T_{FI} / T_{FA}	Ratio $\frac{Ta_{ISO} / Ta}{T_{FI} / T_{FA}}$
6	0.589	1.698	1.51	1.12
13	0.573	1.745	1.47	1.19
18	0.671	1.490	1.23	1.21
h12	0.816	1.225	1.12	1.09
h15	0.633	1.580	1.41	1.12
h30	0.569	1.757	1.69	1.04
			average	1.13

inverse of allowable torque ratio divided by torque reserve ratio

Using the average value of 1.13 obtained from Table 5, Torque Reserve Ratios are calculated from Allowable Torque Ratios from GEARTECH Report 1974 as follows:

$$\frac{T_{FI}}{T_{FA}} = \left(1.13 * \frac{T_a}{T_{aISO}}\right)^{-1}$$

Torque Reserve Ratios calculated with this equation are shown in the third column of Table 6 and plotted in Figure 2.

Table 6- Torque Reserve Ratios calculated from Allowable Torque Ratios from GEARTECH Report 1974 for Strength			
Gearset Ident. No.	Report 1974 Ta / Ta_{ISO}	Report 1974 T_{FI} / T_{FA}	AGMA Study T_{FI} / T_{FA}
2	0.577	1.53	
4	0.562	1.57	
5	0.565	1.57	
6	0.589	1.50	1.51
7	0.565	1.57	
11	0.660	1.34	
12	0.775	1.14	
13	0.573	1.54	1.47
14	0.581	1.52	
15	0.644	1.37	
17	0.654	1.35	
18	0.671	1.32	1.23
h08	0.631	1.40	
h12	0.816	1.08	1.12
h15	0.633	1.40	1.41
h19	0.678	1.31	
h25	0.609	1.45	
h30	0.569	1.56	1.69

Table 6 shows the calculated values match AGMA values within 8% for the six gearsets of the AGMA study.

DISCUSSION

GEARTECH Report 1974 calculated Allowable Torque Ratios based on rated power of the wind turbine multiplied by an application factor of K_A = 1.3, whereas the AGMA study calculated Torque Reserve Ratios using Miner's Rule and actual load spectra.

For a given gearset, the AGMA study found essentially the same Torque Reserve Ratios for a relatively rough load spectrum with significant time above rated power, and a benign spectrum with most time near rated power. This implies the Torque Reserve Ratio is independent of load characteristics, and allows correlation with Allowable Torque Ratios from GEARTECH Report 1974.

Tables 4 and 6 show calculated values of Torque Reserve Ratios match AGMA values within 2% for durability, and within 8% for strength, for the six gearsets of the AGMA study. Therefore, Allowable Torque Ratio and Torque Reserve Ratio are linearly related, at least for the six gearsets of the AGMA study.

The load independence, and the linear relationship between Allowable Torque Ratio and Torque Reserve Ratio, make it possible to obtain Torque Reserve Ratios from the Allowable Torque Ratios for all eighteen gearsets given in GEARTECH Report 1974.

Figure 1 for durability shows all but one gearset fall short of a Torque Reserve Ratio of 1.56 that is required by AGMA/AWEA 6006-AXX. Furthermore, Torque Reserve Ratios vary as much as 29%, ranging from 1.21 to 1.56. As a measure of the significance of the variation, an 11% increase in size (37% increase in mass) would be required to increase the Torque Reserve Ratio of gearset h12 from 1.21 to 1.56.

Figure 2 for strength shows fourteen gearsets fall short of a Torque Reserve Ratio of 1.56 that is required by AGMA/AWEA 6006-AXX. Furthermore, Torque Reserve Ratios vary as much as 45%, ranging from 1.08 to 1.57. A 16% increase in size (56% increase in mass) would be required to increase the Torque Reserve Ratio of gearset h12 from 1.08 to 1.56.

Variations in the Torque Reserve Ratio are caused by differences between ISO 6336 and AGMA 2001 rating methods, coupled with differences in sensitivity of the two methods to changes in geometric variables such as profile shift, helix angle, and normal pressure angle [3].

Variations in the Torque Reserve Ratio prove there is only weak correlation between ISO 6336 and AGMA 2001 gear ratings. Therefore, there is no constant factor for converting between the two methods.

CONCLUSIONS

1. For the eighteen gearsets from GEARTECH 1974, all but one gearset fall short of a Torque Reserve Ratio for durability of 1.56 that is required by AGMA/AWEA 6006-AXX. Furthermore, Torque Reserve Ratios vary as much as 29%, ranging from 1.21 to 1.56. An 11% increase in size (37% increase in mass) would be required to increase the Torque Reserve Ratio of gearset h12 from 1.21 to 1.56.

2. For the eighteen gearsets from GEARTECH 1974, fourteen gearsets fall short of a Torque Reserve Ratio for strength of 1.56 that is required by AGMA/AWEA 6006-AXX. Furthermore, Torque Reserve Ratios vary as much as 45%, ranging from 1.08 to 1.57. A 16% increase in size (56% increase in mass) would be required to increase the Torque Reserve Ratio of gearset h12 from 1.08 to 1.56.

3. Variations in the Torque Reserve Ratio are caused by differences between ISO 6336 and AGMA 2001 rating methods, coupled with differences in sensitivity of the two methods to changes in geometric variables such as profile shift, helix angle, and normal pressure angle.

4. Variations in the Torque Reserve Ratio prove there is only weak correlation between ISO 6336 and AGMA 2001 gear ratings. Therefore, there is no constant factor for converting between the two methods.

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10. AGMA218 Computer Program, copyright GEARTECH Software, Inc. 1985-2002.
11. GEARCALC Computer Program, copyright GEARTECH Software, Inc. 1987-2002.

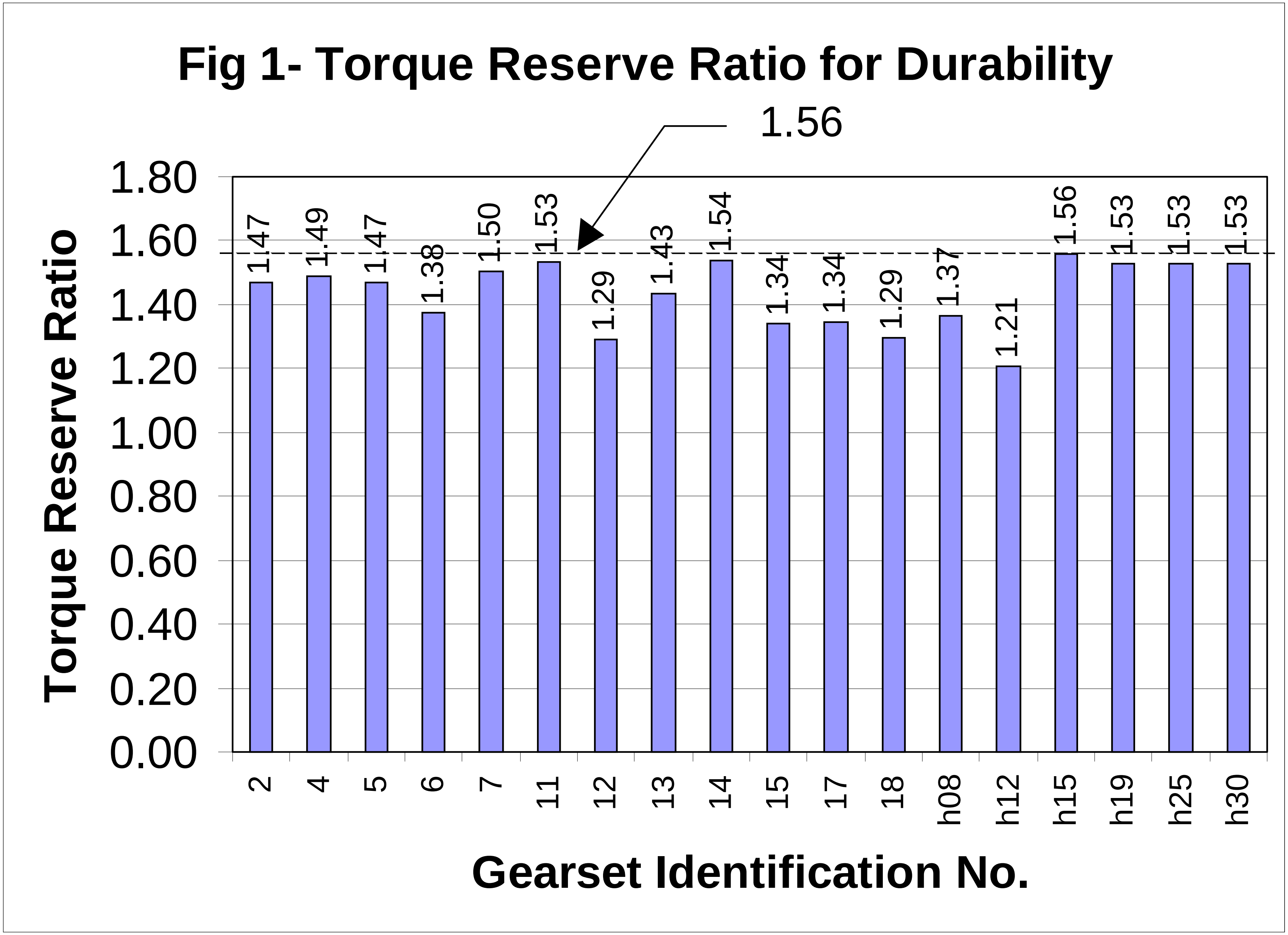
Fig 1- Torque Reserve Ratio for Durability
1.56
Torque Reserve Ratio
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1.47
1.49
1.47
1.38
1.50
1.53
1.29
1.43
1.54
1.34
1.34
1.29
1.37
1.21
1.56
1.53
1.53
1.53
2
4
5
6
7
11
12
13
14
15
17
18
h08
h12
h15
h19
h25
h30
Gearset Identification No.

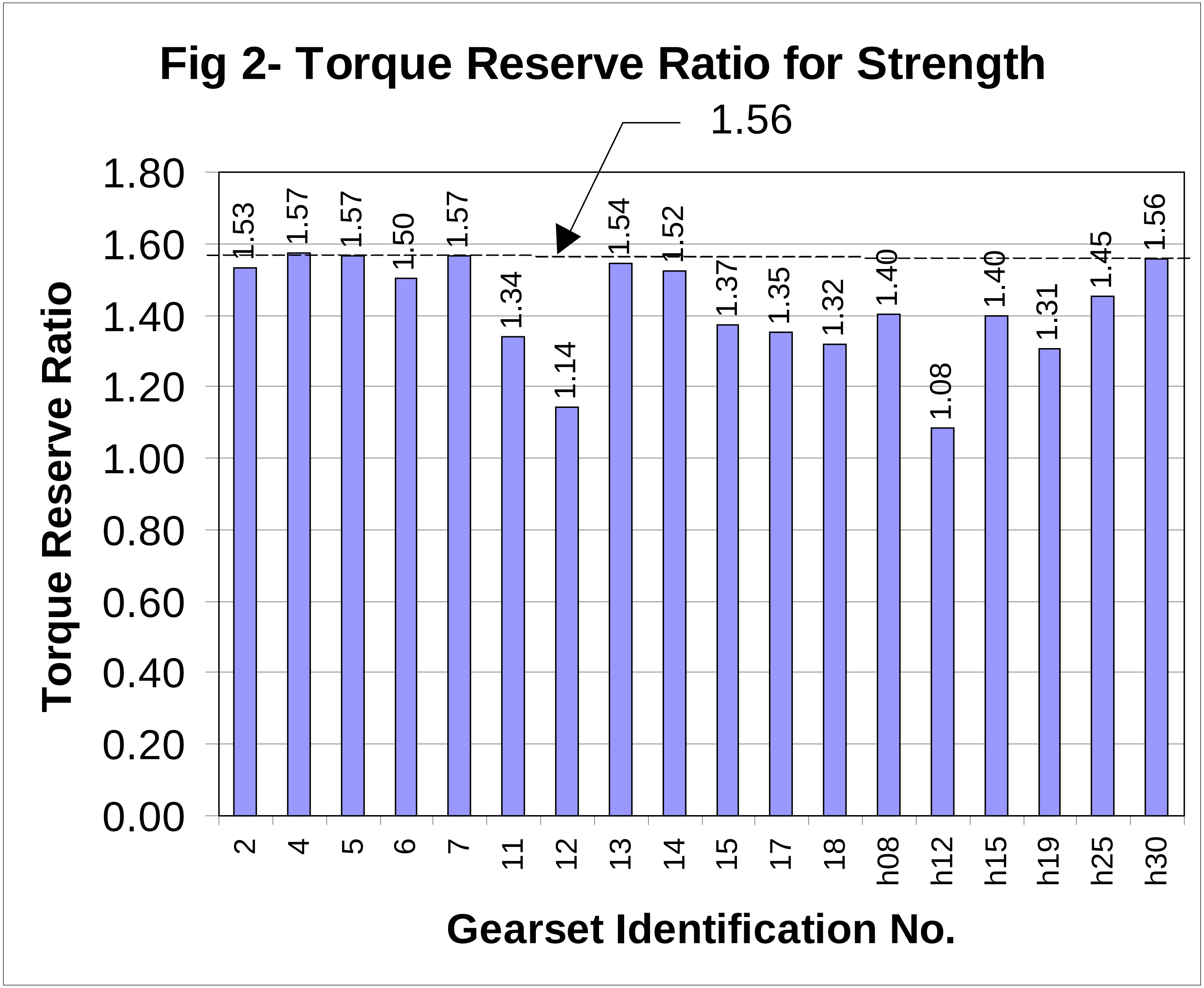

Fig 2- Torque Reserve Ratio for Strength
1.56
Torque Reserve Ratio
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1.53
1.57
1.57
1.50
1.57
1.34
1.14
1.54
1.52
1.37
1.35
1.32
1.40
1.08
1.40
1.31
1.45
1.56
2
4
5
6
7
11
12
13
14
15
17
18
h08
h12
h15
h19
h25
h30
Gearset Identification No.